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(54) CARRIER PHASE TRACKING METHOD AND DEVICE FOR ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING MULTI-CARRIER SYSTEM

(57) Provided in the embodiments of the present disclosure are a carrier phase tracking method and device for an orthogonal frequency division multiplexing (OFDM) multi-carrier system. The method comprises: carrying out frequency domain tracking on a received current OFDM symbol to determine a phase of each subcarrier; on the basis of all subcarrier phase curves, determining an average phase offset between symbols, wherein the average phase offset between symbols is used for characterizing an estimated value of the difference between a carrier phase value of the current OFDM symbol and an estimated value of the carrier phase of the OFDM symbol; and using the average phase offset between the symbols as an input phase for time domain tracking to determine an estimated value of the carrier phase of the current OFDM symbol. According to the carrier phase tracking method and device for an orthogonal frequency division multiplexing (OFDM) multi-carrier system provided in the embodiments of the present disclosure, a double-loop structure with two phase lock loops (PLLs) nested is utilized, and an output result of a frequency domain PLL is input into a time domain PLL after being analyzed and adjusted so that phase changes of a time domain and a frequency domain can be tracked respectively, thereby improving the accuracy of carrier phase tracking on the basis of the OFDM symbol.

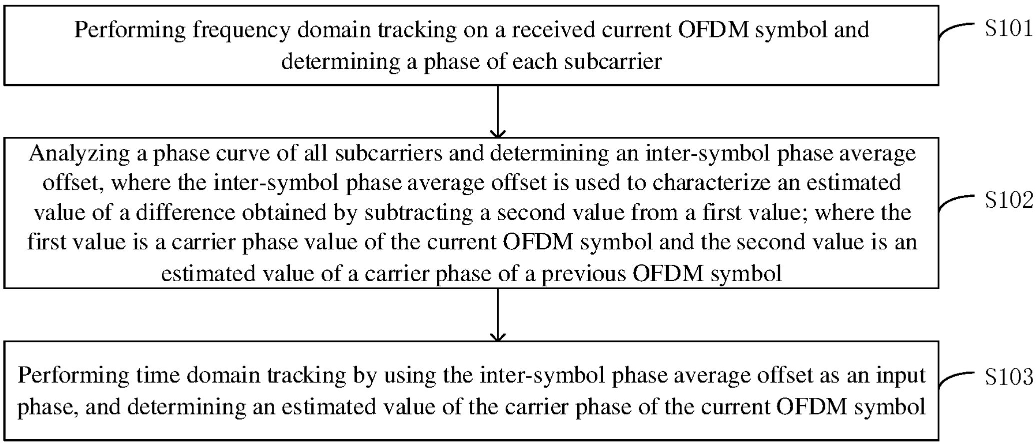

Performing frequency domain tracking on a received current OFDM symbol and determining a phase of each subcarrier
S101
Analyzing a phase curve of all subcarriers and determining an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value; where the first value is a carrier phase value of the current OFDM symbol and the second value is an estimated value of a carrier phase of a previous OFDM symbol
S102
Performing time domain tracking by using the inter-symbol phase average offset as an input phase, and determining an estimated value of the carrier phase of the current OFDM symbol
S103

FIG. 1

Description

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present disclosure claims priority to Chinese Application No. 202010394490.3, filed on May 11, 2020, entitled "Carrier Phase Tracking Method and Device for Orthogonal Frequency Division Multiplexing Multi-Carrier System", which is hereby incorporated by reference in entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of communication, and in particular, to a carrier phase tracking method and apparatus for an orthogonal frequency division multiplexing (OFDM) multi-carrier system.

BACKGROUND

[0003] A carrier phase positioning method is widely used in positioning technology and has a high positioning accuracy. The carrier phase positioning method mainly includes two processes: carrier phase tracking and positioning resolution.
[0004] In the related art, the carrier phase positioning method is mainly applied to global navigation satellite system (GNSS). The traditional carrier phase tracking and positioning method is a mature method in the GNSS single carrier system. The premise of realizing this positioning method is that a receiver can effectively and continuously track the carrier phase of a transmitted signal.
[0005] When the traditional positioning method is applied to the OFDM multi-carrier system, a frequency error occurs between OFDM received signal and transmitted signal due to the reasons such as deviation of crystal oscillator frequency, Doppler offset and inter-subcarrier interference. A phase offset caused by the frequency error will continue to be accumulated with the increase of the number of subcarriers, which seriously affects the tracking accuracy of the carrier phase and reduces the positioning accuracy.

SUMMARY

[0006] Embodiments of the present disclosure provide a carrier phase tracking method and apparatus for an OFDM multi-carrier system, to solve the above problems in the related art.
[0007] An embodiment of the present disclosure provides a carrier phase tracking method for an OFDM multi-carrier system, including:

performing frequency domain tracking on a received current OFDM symbol and determining a phase of each subcarrier;
analyzing a phase curve of all subcarriers and determining .an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol and the second value is an estimated value of a carrier phase of a previous OFDM symbol; and
performing time domain tracking by using the inter-symbol phase average offset as an input phase and determining an estimated value of a carrier phase of the current OFDM symbol.

[0008] In an embodiment, the determining the inter-symbol phase average offset based on the phase curve of all subcarriers, includes:

analyzing the phase curve of all subcarriers in segments and determining a set of estimated values of inter-subcarrier phase change rate;
performing cluster analysis on the set of estimated values of inter-subcarrier phase change rate and determining a category containing the largest number of elements;
averaging elements in the category containing the largest number of elements and determining an inter-subcarrier phase change rate, where the inter-subcarrier phase change rate is used to characterize an estimated value of delay occurring in the current OFDM symbol; and
determining the inter-symbol phase average offset according to the inter-subcarrier phase change rate.

[0009] In an embodiment, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:
adaptively adjusting a parameter value of a loop filter in a frequency domain phase locked loop (PLL) according to the

estimated value of delay occurring in the current OFDM symbol.

[0010] In an embodiment, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:

compensating the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap and a second fixed phase gap, where the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; and the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase.

[0011] In an embodiment, before compensating the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap and the second fixed phase gap, the method further includes:

determining the first fixed phase gap based on a parameter value of the loop filter in the frequency domain PLL, a subcarrier spacing, and the estimated value of delay occurring in the current OFDM symbol; and

determining the second fixed phase gap based on the first fixed phase gap, the inter-symbol phase average offset, and a parameter value of a loop filter in the time domain PLL.

[0012] In an embodiment, when the method is applied to an OFDM multi-carrier system in a time division duplex (TDD) mode, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:

compensating the estimated value of the carrier phase of the current OFDM symbol according to an integer ambiguity change, where the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal including the current OFDM symbol.

[0013] In an embodiment, before the compensating the estimated value of the carrier phase of the current OFDM symbol according to the integer ambiguity change, the method further includes:

performing linear estimation on a frequency offset of a target uplink transmitted signal based on a frequency offset estimated value of the current segment downlink received signal and a frequency offset estimated value of the previous segment downlink received signal, and determining a frequency offset estimated value of the target uplink transmitted signal, where the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal; and

determining the integer ambiguity change according to the frequency offset estimated value of the target uplink transmitted signal.

[0014] In an embodiment, when the method is applied to the OFDM multi-carrier system in the TDD mode, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:

compensating the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap, the second fixed phase gap and the integer ambiguity change, where the first fixed phase gap is a phase gap generated by the frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on the received OFDM symbol; the second fixed phase gap is a phase gap generated by the time domain PLL, and the time domain PLL is used to perform time domain tracking on the input phase; and the integer ambiguity change is the difference obtained by subtracting the integer ambiguity of the previous segment downlink received signal from the integer ambiguity of the current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal including the current OFDM symbol.

[0015] An embodiment of the present disclosure further provides an carrier phase tracking apparatus for an OFDM multi-carrier system, including:

a frequency domain phase locked loop (PLL) module, used to perform frequency domain tracking on a received current OFDM symbol and determine a phase of each subcarrier;

an inner-loop analysis module, used to analyze a phase curve of all subcarriers and determine an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol and the second value is an estimated value of a carrier phase of a previous OFDM symbol; and

a time domain PLL module, used to perform time domain tracking by using the inter-symbol phase average offset as an input phase and determine an estimated value of a carrier phase of the current OFDM symbol.

[0016] In an embodiment, the inner-loop analysis module includes a segment analysis sub-module, a cluster sub-module, a delay estimation sub-module and a phase offset determination sub-module, where the segment analysis sub-module is used to analyze the phase curve of all subcarriers in segments and determine a set of estimated values of inter-subcarrier phase change rate;

the cluster sub-module is used to perform cluster analysis on the set of estimated values of inter-subcarrier phase change rate and determine a category containing the largest number of elements;

the delay estimation sub-module is used to average elements in the category containing the largest number of elements and determine an inter-subcarrier phase change rate, where the inter-subcarrier phase change rate is used to characterize an estimated value of delay occurring in the current OFDM symbol; and

the phase offset determination sub-module is used to determine the inter-symbol phase average offset according to the inter-subcarrier phase change rate.

[0017] In an embodiment, the apparatus further includes a parameter adjustment module used to adaptively adjust a parameter value of a loop filter in a frequency domain PLL according to the estimated value of delay occurring in the current OFDM symbol.

[0018] In an embodiment, the apparatus further includes a first compensation module, where the first compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap and a second fixed phase gap, where the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; and the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase.

[0019] In an embodiment, the apparatus further includes a first fixed phase gap determination module and a second fixed phase gap determination module, where,

the first fixed phase gap determination module is used to determine the first fixed phase gap based on a parameter value of a loop filter in the frequency domain PLL, a subcarrier spacing and an estimated value of delay occurring in the current OFDM symbol; and

the second fixed phase gap determination module is used to determine the second fixed phase gap based on the first fixed phase gap, the inter-symbol phase average offset and a parameter value of a loop filter in the time domain PLL.

[0020] In an embodiment, when the apparatus applied to an OFDM multi-carrier system under TDD mode, the apparatus further includes a second compensation module, where, the second compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to an integer ambiguity change, where the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal including the current OFDM symbol.

[0021] In an embodiment, the apparatus further includes an uplink frequency offset estimation module and an integer ambiguity change determination module, where,

the uplink frequency offset estimation module is used to perform linear estimation on a frequency offset of a target uplink transmitted signal based on a frequency offset estimated value of the current segment downlink received signal and a frequency offset estimated value of the previous segment downlink received signal, and determine a frequency offset estimated value of the target uplink transmitted signal, where the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal; and

the integer ambiguity change determination module is used to determine the integer ambiguity change according to the frequency offset estimated value of the target uplink transmitted signal.

[0022] In an embodiment, when the apparatus is applied to the OFDM multi-carrier system in TDD mode, the apparatus further includes a third compensation module, where,
the third compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap, the second fixed phase gap and the integer ambiguity change, where the first fixed phase gap is a phase gap generated by the frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on the received OFDM symbol; the second fixed phase gap is a phase gap generated by the time domain PLL, and the time domain PLL is used to perform time domain tracking on the input phase; and the integer ambiguity change is the difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal including the current OFDM symbol.

[0023] An embodiment of the present disclosure further provides an electronic equipment, including: a processor and a memory storing a computer program that is executable on the processor, the computer program, when executed by the processor, causes the processor to perform steps of the above-mentioned method.

[0024] An embodiment of the present disclosure further provides a non-transitory computer-readable storage medium having a computer program stored thereon, and the computer program, when executed by a processor, causes the processor to perform the steps of the above-mentioned method.

[0025] In the carrier phase tracking method and apparatus for an OFDM multi-carrier system provided by embodiments of the present disclosure, by using a double-loop structure with two nested PLLs, analyzing and adjusting the output result of the frequency domain PLL and inputting the analyzed and adjusted results into the time domain PLL, the phase change of the time domain and the frequency domain can be tracked respectively and the accuracy of carrier phase tracking for OFDM symbols is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026]

FIG. 1 is a schematic diagram of a carrier phase tracking method for an OFDM multi-carrier system provided by an embodiment of the present disclosure.
FIG. 2 is a schematic diagram of a carrier phase tracking apparatus for the OFDM multi-carrier system provided by an embodiment of the present disclosure.
FIG. 3 is a schematic diagram of an analysis principle for a phase curve of subcarriers provided by an embodiment of the present disclosure.
FIG. 4 is a schematic diagram of a principle for determining an integer ambiguity change provided by an embodiment of the present disclosure.
FIG. 5 is a schematic structural diagram of an electronic equipment provided by an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0027] In order to make the objectives, solutions and advantages of the embodiments of the present disclosure clearer, the solutions according to the embodiments of the present disclosure will be described clearly and completely below with reference to the drawings in the embodiments of the present disclosure. The described embodiments are a part of the embodiments of the present disclosure, rather than all of the embodiments. All other embodiments obtained by a person skilled in the art based on the embodiments in the present disclosure without creative effort are within the protection scope of the present disclosure.

[0028] Embodiments of the present disclosure are directed to a general OFDM signal model including K subcarriers. The subcarrier spacing is represented as f_{scs}, the number of sampling points in one OFDM symbol is N, the length of a cyclic prefix is N_{CP}, the length of one OFDM symbol is N_s, where $N_s = N + N_{CP}$. Due to the delay caused by propagation path and the sampling clock offset and the frequency offset between a receiver and a transmitter, the signal arriving at the receiver has a frequency offset and a sampling time offset with respect to the transmitted signal. The frequency offset is represented by Δf and the sampling time offset is represented by Δt. A frequency domain data obtained by performing fast Fourier transform (FFT) on the received signal including the above sampling clock offset, frequency offset, and sampling time offset is represented by c_k^l and c_k^l is expressed as follows:

$$c_k^l = e^{j\pi\delta f(N-1)/N} e^{-j2\pi(f_c+kf_{scs})\Delta t} \cdot \frac{\sin(\pi\delta f)}{N\sin\left(\frac{\pi\delta f}{N}\right)} H_k^l X_k^l + W_k^l,$$

c_k^l represents the data carried on a *k*th subcarrier of the *l*th OFDM symbol after FFT, where k = 0, ..., K - 1; δf represents a normalized frequency offset after normalizing subcarrier spacing, where $\delta f = \Delta f / f_{scs}$; H_k^l represents a channel impulse response; X_k^l is a complex domain data carried on the *k*th subcarrier of the *l*th OFDM symbol; and W_k^l is a noise term including a noise and inter-carrier interference.

[0029] It can be seen from the expression of c_k^l that a signal carrier phase contains the information of normalized frequency offset δf and delay Δt. Within the same OFDM symbol, the phase offset caused by Δt changes linearly with the increase of the number of subcarriers and this phase change is only reflected in frequency domain phase. Between different OFDM symbols, phase change is caused by the combined action of δf and Δt and this phase change is reflected in time domain phase. Phase-locked loop (PLL) can be used to track the phase change in frequency domain. The linearly changed phase offset corresponds to the inter-subcarrier phase change rate of the phase curve output by the PLL, and then an estimated value of Δt can be calculated according to that.

[0030] For different symbols, the Doppler frequency offset and transmission delay change caused by user's movement will affect the time domain phase of the signal, which can be tracked by using PLL.

[0031] FIG. 1 is a schematic diagram of a carrier phase tracking method for an OFDM multi-carrier system provided by an embodiment of the present disclosure. As shown in FIG. 1, an embodiment of the present disclosure provides a carrier phase tracking method for the OFDM multi-carrier system, which is performed by a carrier phase tracking apparatus for OFDM multi-carrier system. The method includes the following steps.

[0032] S101: performing frequency domain tracking on a received current OFDM symbol and determining a phase of each subcarrier.

[0033] In an embodiment, the carrier phase tracking apparatus for an OFDM multi-carrier system in the embodiments of the present disclosure is used in a receiver for processing a signal to obtain information of a carrier phase. A OFDM symbol arrives at the receiver after passing through a channel, is subjected to down-conversion and time-domain discrete sampling and enters the carrier phase tracking apparatus for OFDM multi-carrier system for performing carrier phase tracking.

[0034] FIG. 2 is a schematic diagram of a carrier phase tracking apparatus for an OFDM multi-carrier system provided by an embodiment of the present disclosure. As shown in FIG. 2, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by the embodiment of the present disclosure has a double-loop PLL structure, including a frequency domain PLL module, an inner-loop analysis module and a time domain PLL module.

[0035] The frequency domain PLL module is also referred to as an inner-loop PLL, or inner-loop for short, which is used to perform frequency domain tracking on the received lth OFDM symbol and determine the phase of each subcarrier. The frequency domain PLL module includes an inner-loop multiplier, a phase error discriminator (PED), an inner-loop filter and an inner-loop numerical control oscillator (NCO).

[0036] After the input sample data r_i^l of the lth OFDM symbol is corrected by the output value of an outer-loop NCO, the corrected input sample data is converted into frequency domain data c_k^l by the FFT operator, and enters the inner-loop PLL. r_i^l represents the ith time domain sampling data in the lth OFDM symbol, where $i = 0, ..., N - 1$. c_k^l represents the data carried on the k th subcarrier of the lth OFDM symbol after FFT, where $k = 0, ..., K - 1$.

[0037] After the frequency domain data c_k^l is corrected by the output value of the inner-loop NCO, the corrected frequency domain data enter the PED. The corrected frequency domain data is processing by PED to output the phase gap $\varepsilon_{k,f}$, where $\varepsilon_{k,f}$ represents the phase gap between the kth subcarrier and the (k - 1)th output of the inner-loop NCO, $\varepsilon_{k,f}$ is obtained by conjugate multiplication of the corrected frequency domain data and a known PRS sequence, and $\varepsilon_{k,f}$ remains unchanged when the phase of the inner-loop PLL is locked.

[0038] The phase gap $\varepsilon_{k,f}$ enters the inner-loop NCO after passing through the inner-loop filter. The inner-loop NCO outputs subcarrier phase $\hat{\Psi}_{k,l}$, where $\hat{\Psi}_{k,l}$ is obtained by accumulating the outputs of the inner-loop filter corresponding to the previous k subcarriers, and is used to correct the phase of the (k + 1)th subcarrier. After the phase of the inner-loop PLL is locked, $\hat{\Psi}_{k,l}$ changes linearly with the increase of the number of subcarriers.

[0039] Considering the delay change caused by the propagation environment and user movement, the parameter α_f of the inner-loop filter can be adaptively adjusted during the phase tracking process.

[0040] S102: analyzing a phase curve of all subcarriers and determining an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value; where the first value is a carrier phase value of the current OFDM symbol and the second value is an estimated value of a carrier phase of a previous OFDM symbol.

[0041] In an embodiment, after K frequency domain data of one OFDM symbol are all processed by the frequency domain PLL, the phase output $\hat{\Psi}_l$ corresponding to each subcarrier can be obtained, where $\hat{\Psi}_l = \{\hat{\Psi}_{0,l}, ..., \hat{\Psi}_{K-1,l}\}$. The inner-loop analysis module is used to analyze the phase curves of all subcarriers and determine the inter-symbol phase average offset.

[0042] In an embodiment, the analyzing the phase curve of all subcarriers and determining the phase average offset can include performing fitting on the phase curve of all subcarriers and determining an intercept value of curve fitting, where the intercept value can be understood as the above-mentioned phase average offset.

[0043] FIG. 3 is a schematic diagram of an analysis principle for a phase curve of subcarriers provided by an embodiment of the present disclosure. As shown in FIG. 3, the abscissa is the subcarrier serial number, and the ordinate is the phase value. The solid line in FIG. 3 is the phase curve of subcarriers. The dotted line in FIG. 3 is a straight line obtained by linear analysis. After obtaining this straight line, the inter-symbol phase average offset can be determined, which is equivalent to determining the intercept value of the curve fitting.

[0044] The inter-symbol phase average offset is represented by $\hat{\varphi}_{in}^{l}$, and $\hat{\varphi}_{in}^{l}$ is used to characterize the estimated value of the difference obtained by subtracting the second value from the first value. The first value refers to the carrier phase value of the current OFDM symbol and the second value refers to the estimated value of the carrier phase of the previous OFDM symbol.

[0045] S103: performing time domain tracking by using the inter-symbol phase average offset as an input phase, and determining an estimated value of the carrier phase of the current OFDM symbol.

[0046] In an embodiment, after obtaining the inter-symbol phase average offset $\hat{\varphi}_{in}^{l}$, the time domain tracking is performed by using the inter-symbol phase average offset as the input phase, and the estimated value $\hat{\varphi}_l$ of the carrier phase of the current OFDM symbol is determined.

[0047] For example, the inter-symbol phase average offset is used as the input of the time domain PLL, the time domain tracking is performed through the time domain PLL, and the estimated value $\hat{\varphi}_l$ of the carrier phase of the current OFDM symbol is determined.

[0048] The time domain PLL module is also referred to as outer-loop PLL, or outer-loop for short. The time domain PLL module includes an outer-loop multiplier, an outer-loop filter and an outer-loop NCO.

[0049] After the input data $\hat{\varphi}_{in}^{l}$ is processed by the outer-loop filter, the processed input data enters the outer-loop NCO to output the estimated value $\hat{\varphi}_l$ of the carrier phase of the current OFDM symbol, where $\hat{\varphi}_l$ is obtained by accumulating the outputs of the outer-loop filter corresponding to the previous l OFDM symbols as the tracking phase of the outer-loop PLL output, and is used to correct the phase of the $(l + 1)$th OFDM symbol.

[0050] The parameter α_t of the outer-loop filter can be configured as a fixed value.

[0051] It should be noted that for the same OFDM symbol, depending on the difference of the range and order of the data c_k^l inputted to the inner-loop PLL, the carrier phase outputted by the outer-loop PLL is also different. The carrier phase outputted by the outer-loop PLL refers to the phase corresponding to the first subcarrier inputted to the inner-loop. Therefore, the overall structure of the double-loop PLL can be appropriately expanded as required. The entire PLL can be expanded into a structure having multiple parallel PLLs, which can output phase tracking results corresponding to multiple required subcarrier frequency points respectively.

[0052] In the carrier phase tracking method for the OFDM multi-carrier system provided by embodiments of the present disclosure, by using a double-loop structure with two nested PLLs, and inputting the output result of the frequency domain PLL after being analyzed and adjusted into the time domain PLL, phase changes in both the time domain and the frequency domain can be tracked and the accuracy of carrier phase tracking for OFDM symbols is improved.

[0053] Based on any of the above-mentioned embodiments, in an embodiment, the analyzing phase curve of all subcarriers and determining an inter-symbol phase average offset includes:

analyzing the phase curve of all subcarriers in segments and determining a set of estimated values of inter-subcarrier phase change rate;
performing cluster analysis on the set of estimated values of inter-subcarrier phase change rate and determining a category containing the largest number of elements;
averaging elements in the category containing the largest number of elements and determining an inter-subcarrier phase change rate used for characterizing an estimated value of delay occurring in the current OFDM symbol; and
determining the inter-symbol phase average offset according to the inter-subcarrier phase change rate.

[0054] In an embodiment, the analyzing the phase curve of all subcarriers in segments and determining a set of estimated value of inter-subcarrier phase change rate can include performing fitting on the phase curve of all subcarriers in segments and determining a set of estimated values of the curve slope. The curve slope here can be understood as the above-mentioned inter-subcarrier phase change rate.

[0055] In the embodiments of the present disclosure, after K frequency domain data are processed in the inner-loop, the phase output $\hat{\Psi}_l$ corresponding to each subcarrier can be obtained, where $\hat{\Psi}_l = \{\hat{\Psi}_{0,l}, ..., \hat{\Psi}_{K-1,l}\}$, and the phase output contains the delay information. The phase curve of $\hat{\Psi}_l$ is analyzed to obtain the estimated value $\Delta\hat{t}$ of the delay and the phase $\hat{\varphi}_{in}^{l}$ inputted to the outer loop from the inner-loop. For example, the analyzing process is shown as follow.

[0056] Firstly, the phase curve in the inner-loop is analyzed in segments (the segments can be overlapped) and a set of estimated values of inter-subcarrier phase change rate is obtained.

[0057] Secondly, cluster analysis is performed on the set of estimated values of inter-subcarrier phase change rate, and a radius *e_dt* for category is set according to the accuracy requirements, where *e_dt* is used to classify the set of estimated values of inter-subcarrier phase change rate to determine the category containing the largest number of elements.

[0058] Thirdly, the elements in the category containing the largest number of elements are averaged and the inter-subcarrier phase change rate is determined, where the inter-subcarrier phase change rate is used to characterize an estimated value $\hat{\Delta t}^{l}$ of delay occurring in the current OFDM symbol.

[0059] Finally, the inter-symbol phase average offset is determined according to the inter-subcarrier phase change rate. As shown in FIG. 3, the result obtained by analyzing the phase curve of all subcarriers in segments is a straight line, and the inter-symbol phase average offset can be determined after obtaining this straight line.

[0060] In the carrier phase tracking method for the OFDM multi-carrier system provided by embodiments of the present disclosure, by analyzing in segments and performing cluster analysis, the accuracy of estimating the inter-symbol phase average offset can be improved and the accuracy of carrier phase tracking of OFDM symbols can be further improved.

[0061] Based on any of the above-mentioned embodiments, in an embodiment, after the determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:
adaptively adjusting a parameter value of a loop filter in a frequency domain PLL according to the estimated value of delay occurred in the current OFDM symbol.

[0062] In the embodiment of the present disclosure, considering the delay change caused by the propagation environment and user movement, the parameter α_f of the inner-loop filter can be adaptively adjusted during the phase tracking process.

[0063] The parameter value of the loop filter in the frequency domain phase locked loop (PLL) is adaptively adjusted according to the estimated value $\hat{\Delta t}^{l}$ of delay occurred in the current OFDM symbol.

[0064] Since the parameter α_f of the inner-loop filter changes slowly, the parameter of the inner-loop filter may be adjusted for each OFDM symbol, or the parameter of the inner-loop filter may be adjusted once every time a plurality of OFDM symbols are processed.

[0065] The parameter α_f of the inner-loop filter can be adaptively adjusted according to a preset corresponding relationship. The corresponding relationship between the estimated value $\hat{\Delta t}$ of delay and the parameter α_f of the inner-loop filter can be as shown in table 1.

Table 1 Corresponding relationship between $\hat{\Delta t}$ and α_f

Estimated value $\hat{\Delta t}$ of delay	Value of α_f
< 15 ns	0.1
15-30 ns	0.2
30-70 ns	0.3
70-900 ns	0.5
0.9-7 us	0.85
7-9.6 us	0.9
>9.6 us	0.98

[0066] In the carrier phase tracking method for the OFDM multi-carrier system provided by embodiments of the present disclosure, by adaptively adjusting the parameter of the inner-loop filter, the delay change caused by the propagation environment or user movement can be avoided and the accuracy of tracking carrier phase of OFDM symbols can be further improved.

[0067] Based on any of the above-mentioned embodiments, in an embodiment, after the determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:
compensating the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap and a second fixed phase gap, where the first fixed phase gap is a phase gap generated by the frequency domain PLL which is used to perform frequency domain tracking on a received OFDM symbol, and the second fixed phase gap is a phase gap generated by the time domain PLL which is used to perform time domain tracking on an input phase.

[0068] In an embodiment of the present disclosure, both the inner-loop PLL and the outer-loop PLL are first-order PLL.

Since there is a fixed phase gap when the linearly changing phase is estimated by first-order PLL, the value of the gap needs to be calculated and compensated on the output phase.

[0069] The fixed phase gap generated by the inner-loop PLL is represented by gap_1, the fixed phase gap generated by the outer-loop PLL is represented by gap_2, and the output phase of the outer-loop PLL is used as the input of the inner-loop PLL. Therefore, the value of gap_2 is associated with gap_1.

[0070] After both gap_1 and gap_2 are determined, the estimated value of the carrier phase of the current OFDM symbol can be compensated. The formula is expressed as follows:

$$\hat{\varphi}_l' = \hat{\varphi}_l + gap_2,$$

where $\hat{\varphi}_l'$ is the compensated carrier phase, $\hat{\varphi}_l$ is the estimated value of the carrier phase outputted by the outer-loop PLL, and gap_2 is the fixed phase gap generated by the outer-loop PLL.

[0071] In the carrier phase tracking method for the OFDM multi-carrier system provided by embodiments of the present disclosure, by compensating the estimated value of the carrier phase, the effect of the phase gap generated by the frequency domain PLL and the phase gap generated by the time domain PLL on the results can be avoided, and further the accuracy of tracking carrier phase of OFDM symbols can be improved.

[0072] Based on any of the above-mentioned embodiments, in an embodiment, before the compensating the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap and the second fixed phase gap, the method further includes:

determining the first fixed phase gap based on the parameter value of the loop filter in the frequency domain PLL, a subcarrier spacing, and the estimated value of delay occurred in the current OFDM symbol; and
determining the second fixed phase gap based on the first fixed phase gap, the inter-symbol phase average offset, and the parameter value of the loop filter in the time domain PLL.

[0073] In an embodiment of the present disclosure, the first fixed phase gap is determined based on the parameter value of the loop filter in the frequency domain PLL, the subcarrier spacing, and the estimated value of delay occurring in the current OFDM symbol.

[0074] The second fixed phase gap is determined based on the first fixed phase gap, the inter-symbol phase average offset, and the parameter value of the loop filter in the time domain PLL.

[0075] In an embodiment, the steps of determining the first fixed phase gap or the second fixed phase gap are as follows.

[0076] The inner-loop PLL estimates the linear change of the frequency domain phase. In an ideal situation, after the inner-loop PLL is locked, the step amount of the output phase is the same as the phase change between adjacent subcarriers in the frequency domain, which is expressed by the formula as follows:

$$\alpha_f \varepsilon_{k,f} = 2\pi f_{scs} \Delta t.$$

where $\varepsilon_{k,f} = \Psi_{k,l} - \hat{\Psi}_{k-1,l}$ is the difference between the phase of the kth subcarrier outputted by the PED and the (k - 1)th phase output from the inner-loop PLL. The fixed phase gap gap_1 in the inner-loop PLL is the difference between the phase of the k th subcarrier and the corresponding k th phase output from the inner-loop PLL, which is expressed by the formula as follows:

$$gap_1 = \Psi_{k,l} - \hat{\Psi}_{k,l} = \Psi_{k,l} - \left(\hat{\Psi}_{k-1,l} + \alpha_f \varepsilon_{k,f}\right) = \left(1 - \alpha_f\right)\varepsilon_{k,f}.$$

[0077] Combining the above two formulas, the expression of the fixed phase gap generated by the inner-loop PLL can be obtained by the formula as follows:

$$gap_1 = \frac{1-\alpha_f}{\alpha_f} * 2\pi f_{scs} \Delta t.$$

[0078] The outer loop estimates the phase change in the time domain, that is, $\alpha_t \hat{\varphi}_{in}^l$. $\varphi_{in}^l = \varphi_l - \hat{\varphi}_{l-1}$ represents the difference between the phase of the lth OFDM symbol and the phase output corresponding to the (l - 1) th symbol. Considering the existence of gap_1 of the inner-loop, $\varphi_{in}^{l} = \hat{\varphi}_{in}^{l} + gap_1$.

[0079] The fixed phase gap generated by the outer-loop PLL is the difference between the phase of the lth OFDM symbol and the corresponding lth phase output of the outer loop, which is expressed by the formula as follows:

$$gap_2 = \varphi_l - \hat{\varphi}_l = \varphi_l - \left(\hat{\varphi}_{l-1} + \alpha_t \hat{\varphi}_{in}^{l}\right) = \varphi_{in}^{l} - \alpha_t \hat{\varphi}_{in}^{l} = \hat{\varphi}_{in}^{l} + gap_1 - \alpha_t \hat{\varphi}_{in}^{l}.$$

[0080] From this, the fixed phase gap of the outer-loop PLL can be obtained and is expressed by the formula as follows:

$$gap_2 = (1 - \alpha_t)\hat{\varphi}_{in}^{l} + gap_1.$$

[0081] In the carrier phase tracking method for OFDM multi-carrier system provided by embodiments of the present disclosure, by determining the phase gap generated by the frequency domain PLL according to the parameter value of the loop filter in the frequency domain PLL, the subcarrier spacing, and the estimated value of delay occurred in the current OFDM symbol, the determined phase gap generated by the frequency domain PLL is more accurate; by determining the phase gap generated by the time domain PLL according to the correlation between the frequency domain PLL and the time domain PLL, the determined phase gap generated by the time domain PLL is more accurate, and further the accuracy of tracking carrier phase of OFDM symbols is improved.

[0082] Based on any of the above-mentioned embodiments, in an embodiment, when applied to an OFDM multi-carrier system under a time division duplex (TDD) mode, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:
compensating the estimated value of the carrier phase of the current OFDM symbol according to an integer ambiguity change, where the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a downlink received signal of previous segment from an integer ambiguity of the downlink received signal of current segment, the downlink received signal of the current segment is a segment of downlink received signal including the current OFDM symbol.

[0083] In an embodiment of the present disclosure, since the received signal in time division duplex (TDD) mode is discontinuous, the phase estimation needs to be performed again every preset time duration. In an embodiment, the integer ambiguity change needs to be determined, and the estimated value of the carrier phase of the current OFDM symbol is compensated according to the integer ambiguity change. The integer ambiguity change is the difference obtained by subtracting the integer ambiguity of the downlink received signal of previous segment from the integer ambiguity of the downlink received signal of the current segment, the downlink received signal of the current segment is a segment of downlink received signal including the current OFDM symbol. The formula for compensating is expressed as follows:

$$\hat{\varphi}_l' = \hat{\varphi}_l + \Delta N \cdot 2\pi,$$

where $\hat{\varphi}_l'$ is the compensated carrier phase, $\hat{\varphi}_l$ is the estimated value of the carrier phase outputted by the outer-loop PLL, and ΔN is the integer ambiguity change.

[0084] In the carrier phase tracking method for OFDM multi-carrier system provided by embodiments of the present disclosure, by compensating the estimated value of the carrier phase of the current OFDM symbol using the integer ambiguity change for the case where the received signal is discontinuous in the TDD system, the accuracy of carrier phase tracking of OFDM symbols is improved.

[0085] Based on any of the above-mentioned embodiments, in an embodiment, before the compensating the estimated value of the carrier phase of the current OFDM symbol according to the integer ambiguity change, the method further includes:

performing linear estimation on a frequency offset of a target uplink transmitted signal based on a frequency offset estimated value of the current segment downlink received signal and a frequency offset estimated value of the previous segment downlink received signal, and determining a frequency offset estimated value of the target uplink transmitted signal, where the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal; and
determining the integer ambiguity change according to the frequency offset estimated value of the target uplink

transmitted signal.

[0086] In an embodiment, after a plurality of continuous OFDM symbols enter the double-loop PLL structure, a plurality of outer loop output phases $\{\hat{\varphi}_l | l = 0, ...\}$ are obtained correspondingly, and the outer loop output phases include frequency offset information. The estimated value $\delta\hat{f}$ of the frequency offset can be obtained by calculating an average value $\Delta\varphi$ of differences between the outer loop output phases of adjacent OFDM symbols, which can be expressed by the formula as follows:

$$\delta\hat{f} = \frac{\overline{\Delta\varphi}}{2\pi(N+N_{CP})} N f_{scs};$$

$\delta\hat{f}$ is the estimated value of the frequency offset, $\overline{\Delta\varphi}$ is the average value of differences between the outer loop output phases, N is the number of sampling points in one OFDM symbol, N_{CP} is the length of cyclic prefix, and f_{scs} is the subcarrier spacing.

[0087] In the embodiments of the present disclosure, by performing linear estimation on the frequency offset of the uplink signal at an interval between two segment adjacent downlink signals using the frequency offset estimated values of the two segment adjacent downlink signals, and calculating the variation amount of carrier phase within the interval uplink time (for example, 5 ms), an estimated integer ambiguity of downlink signals can be obtained.

[0088] In an embodiment, the steps of determining the integer ambiguity change ΔN are as follows.

[0089] Linear estimation is firstly performed on the frequency offset of the target uplink transmitted signal based on the frequency offset estimated value of the current segment downlink received signal and the frequency offset estimated value of the previous segment downlink received signal, and then an estimated value of the frequency offset of the target uplink transmitted signal is determined, where the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal.

[0090] FIG. 4 is a schematic diagram of a principle for determining an integer ambiguity change provided by an embodiment of the present disclosure. As shown in FIG. 4, the two segments of received adjacent downlink signals are represented by s1 and s3, respectively. According to the output results of the outer-loop PLL, the estimated value of the carrier phase of the s1 segment is represented as a solid line segment in the FIG. 4, and the estimated value of the carrier phase of the s3 segment is represented as a solid line segment in the FIG. 4. The frequency offset estimated value of the s1 segment is $\delta\hat{f}_1$ and the frequency offset estimated value of the s3 segment is $\delta\hat{f}_3$, and the uplink signal within the time (the time length is determined by the system configuration, for example, 5 ms) between s1 and s3 segments is represented by s2. According to the empirical value in practical application, the upper and lower bounds of the possible frequency offset are respectively set as $\pm$ 0.05, and the range of phase hopping that may occur within 5 ms (70 OFDM symbols) is $\pm$ 28 rad ($\pm$ 0.05*70*2π*(N+N_{CP})/N), which is about 4.5 integer cycles. Therefore, the cycle slip variable that occurs in the s3 segment is limited to [-4, 4]. By shifting the estimated value of the carrier phase of the s3 segment (the solid line of the s3 segment in FIG. 4) upwards and downwards in units of 2π, 9 parallel curves can be obtained, which are approximately straight line segments. In FIG. 4, only 7 lines are drawn in the s3 segment as an example. Assuming that the frequency offset of the uplink signal s2 segment remains unchanged, 9 estimated values of δf_2 can be obtained, and the one of the 9 estimated values that makes the variance of $\delta\hat{f}_1$, δf_2 and $\delta\hat{f}_3$ be smallest is selected as the estimated value of δf_2, and the mathematical expression is as follows:

$$\delta\hat{f}_2 = arg \min_{\delta\hat{f}_{2,i}} \sqrt{\left|\delta\hat{f}_1 - \delta\hat{f}_{2,i}\right|^2 + \left|\delta\hat{f}_3 - \delta\hat{f}_{2,i}\right|^2},$$

where i = 1, ...,9.

[0091] Then, the integer ambiguity change is determined according to the frequency offset estimated value of the target uplink transmitted signal.

[0092] As shown in FIG. 4, after the estimated value of δf_2 is determined, it can be determined that the s2 segment carrier phase estimated value curve is the solid line in FIG. 4 among 9 possible carrier phase estimated value curves (in FIG. 4, only 7 lines are drawn in the s2 segment as an example). Then, the double solid line in the s3 segment in FIG. 4 represents the carrier phase value of the s3 segment after compensating the integer ambiguity. The phase deviation of the s3 segment double solid line relative to the s3 segment solid line is divided by 2π, and then the offset ΔN of integer ambiguity of the s3 segment relative to the s1 segment is obtained.

[0093] In the carrier phase tracking method for OFDM multi-carrier system provided by the embodiments of the present disclosure, by performing linear estimation on the frequency offset of the uplink signal at the interval using the frequency offset estimated values of the two segment adjacent downlink signals, and determining the integer ambiguity change according to the frequency offset estimated value of the uplink transmitted signal, the obtained integer ambiguity change is more accurate and the accuracy of tacking carrier phase of OFDM symbols is further improved.

[0094] Based on any of the above-mentioned embodiments, in an embodiment, when the method is applied to the OFDM multi-carrier system in TDD mode, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further includes:

compensating the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap, the second fixed phase gap and the integer ambiguity change, where the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase; and the integer ambiguity change is the difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is one segment downlink received signal including the current OFDM symbol.

[0095] In an embodiment of the present disclosure, since the received signal in time division duplex (TDD) mode is discontinuous, the phase estimation needs to be performed again every preset time duration and because there is a phase gap in the inner-loop PLL and the outer-loop PLL, the fixed phase gaps of the inner-loop PLL and the outer-loop PLL and the integer ambiguity change need to be determined, and then the estimated value of the carrier phase of the current OFDM symbol is compensated according to the fixed phase gaps of the inner-loop PLL and the outer-loop PLL and the integer ambiguity change. The integer ambiguity change is the difference obtained by subtracting the integer ambiguity of the previous segment downlink received signal from the integer ambiguity of the current segment downlink received signal, and the current segment downlink received signal is one segment downlink received signal including the current OFDM symbol. The formula for performing compensation is expressed as follows:

$$\hat{\varphi}_l' = \hat{\varphi}_l + gap_2 + \Delta N \cdot 2\pi;$$

where $\hat{\varphi}_l'$ is the carrier phase after compensation, $\hat{\varphi}_l$ is the estimated value of the carrier phase outputted by the outer-loop PLL, gap_2 is the fixed phase gap of the outer-loop PLL, where the value of the gap_2 is associated with gap_1, gap_1 is the fixed phase gap of the inner-loop PLL, and ΔN is the integer ambiguity change.

[0096] In the carrier phase tracking method for the OFDM multi-carrier system provided by the embodiments of the present disclosure, by compensating the estimated value of the carrier phase of the current OFDM symbol according to the fixed phase gap of the frequency domain PLL, the fixed phase gap of the time domain PLL and the integer ambiguity change, the compensating effect is improved and the accuracy of carrier phase tracking for OFDM symbols is further improved.

[0097] FIG. 2 is a schematic diagram of a carrier phase tracking apparatus for OFDM multi-carrier system provided by an embodiment of the present disclosure. As shown in FIG. 2, the carrier phase tracking apparatus for OFDM multi-carrier system provided by the embodiment of the present disclosure includes a frequency domain PLL module, an inner-loop analysis module and a time domain PLL module.

[0098] The frequency domain PLL module is used to perform frequency domain tracking on a received current OFDM symbol and determine a phase of each subcarrier. The inner-loop analysis module is used to analyze a phase curve of all subcarriers and determine an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol, and the second value is an estimated value of a carrier phase of a previous OFDM symbol. The time domain PLL module is used to perform time domain tracking by using the inter-symbol phase average offset as an input phase and determine an estimated value of a carrier phase of the current OFDM symbol.

[0099] In an embodiment, the frequency domain PLL module includes an inner-loop multiplier, a phase error discriminator (PED), an inner-loop filter and an inner-loop numerical control oscillator (NCO).

[0100] After the input sample data r_i^l of the current (lth) OFDM symbol is corrected by the output value of an outer-loop NCO, the corrected input sample data is converted into frequency domain data c_k^l by the FFT operator, and enters the inner-loop PLL. r_i^l represents the ith time domain sampling data in the lth OFDM symbol, where $i = 0, ..., N - 1$. c_k^l represents the data carried on the k th subcarrier of the l th OFDM symbol after FFT, where $k = 0, ..., K - 1$.

[0101] After the frequency domain data c_k^l is corrected by the output value of the inner-loop NCO, the corrected frequency domain data enter the PED. The corrected frequency domain data is processing by PED to output the phase gap $\varepsilon_{k,f}$, where $\varepsilon_{k,f}$ represents the phase gap between the kth subcarrier and the (k - 1)th output of the inner-loop NCO, $\varepsilon_{k,f}$ is obtained by conjugate multiplication of the corrected frequency domain data and a known PRS sequence, and $\varepsilon_{k,f}$ remains unchanged when the phase of the inner-loop PLL is locked.

[0102] The phase gap $\varepsilon_{k,f}$ enters the inner-loop NCO after passing through the inner-loop filter. The inner-loop NCO outputs subcarrier phase $\hat{\Psi}_{k,l}$, where $\hat{\Psi}_{k,l}$ is obtained by accumulating the outputs of the inner-loop filter corresponding to the previous k subcarriers, and is used to correct the phase of the (k + 1)th subcarrier. After the phase of the inner-loop PLL is locked, $\hat{\Psi}_{k,l}$ changes linearly with the increase of the number of subcarriers.

[0103] After K frequency domain data of one OFDM symbol are all processed by the frequency domain PLL, the phase output $\hat{\Psi}_l$ corresponding to each subcarrier can be obtained, where $\hat{\Psi}_l = \{\hat{\Psi}_{0,l}, ..., \hat{\Psi}_{K-1,l}\}$. The inner-loop analysis module is used to analyze the phase curve of all subcarriers and determine the inter-symbol phase average offset. The inter-symbol phase average offset is represented by $\hat{\varphi}_{in}^l$, and $\hat{\varphi}_{in}^l$ is used to characterize the estimated value of the difference obtained by subtracting the second value from the first value. The first value refers to the carrier phase value of the current OFDM symbol, and the second value refers to the estimated value of the carrier phase of the previous OFDM symbol.

[0104] After determining the inter-symbol phase average offset $\hat{\varphi}_{in}^l$, the time domain tracking is performed by using the inter-symbol phase average offset as the input phase, and the estimated value $\hat{\varphi}_l$ of the carrier phase of the current OFDM symbol is determined.

[0105] For example, the inter-symbol phase average offset is used as the input of the time domain PLL, the time domain tracking is performed through the time domain PLL, and the estimated value $\hat{\varphi}_l$ of the carrier phase of the current OFDM symbol is determined.

[0106] The time domain PLL module includes an outer-loop multiplier, an outer-loop filter, and an outer-loop NCO.

[0107] After the input data $\hat{\varphi}_{in}^l$ is processed by the outer-loop filter, the processed input data enters the outer-loop NCO to output the estimated value $\hat{\varphi}_l$ of the carrier phase of the current OFDM symbol, where $\hat{\varphi}_l$ is obtained by accumulating the outputs of the outer-loop filter corresponding to the previous l OFDM symbols as the tracking phase of the outer-loop PLL output, and is used to correct the phase of the (l + 1)th OFDM symbol.

[0108] The carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0109] In the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure, by using a double-loop structure with two nested PLLs, and inputting the output result of the frequency domain PLL after being analyzed and adjusted into the time domain PLL, the phase changes in both the time domain and the frequency domain can be tracked respectively and the accuracy of carrier phase tracking for OFDM symbols is improved.

[0110] Based on any of the above-mentioned embodiments, in an embodiment, the inner-loop analysis module includes a segment analysis sub-module, a cluster sub-module, a delay estimation sub-module and a phase offset determination sub-module, where:

the segment analysis sub-module is used to analyze the phase curve of all subcarriers in segments and determine a set of estimated value of inter-subcarrier phase change rate;
the cluster sub-module is used to perform cluster analysis on the set of estimated value of inter-subcarrier phase change rate and determine a category containing the largest number of elements;
the delay estimation sub-module is used to average elements in the category containing the largest number of elements and determine an inter-subcarrier phase change rate, where the inter-subcarrier phase change rate is used to characterize an estimated value of delay occurring in the current OFDM symbol; and
the phase offset determination sub-module is used to determine the inter-symbol phase average offset according to the inter-subcarrier phase change rate.

[0111] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0112] In the carrier phase tracking apparatus for the OFDM multi-carrier system provided by the embodiments of the present disclosure, by analyzing in sections and then performing cluster analysis, the estimation accuracy of the inter-symbol phase average offset is improved and the accuracy of carrier phase tracking for OFDM symbols is further improved.

[0113] Based on any of the above-mentioned embodiments, in an embodiment, the apparatus further includes a parameter adjustment module.

[0114] In an embodiment, the parameter adjustment module is used to adaptively adjust a parameter value of a loop filter in a frequency domain PLL according to the estimated value of delay occurring in the current OFDM symbol.

[0115] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0116] In the carrier phase tracking apparatus for the OFDM multi-carrier system provided by the embodiments of the present disclosure, by adaptively adjusting the parameter of the inner-loop filter, the delay change caused by the propagation environment or user movement is avoided and the accuracy of carrier phase tracking of OFDM symbols is further improved.

[0117] Based on any of the above-mentioned embodiments, in an embodiment, the apparatus further includes a first compensation module.

[0118] In an embodiment, the first compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap and a second fixed phase gap, where the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; and the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase.

[0119] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0120] In the carrier phase tracking apparatus for OFDM multi-carrier system provided by the embodiments of the present disclosure, by compensating the estimated value of the carrier phase, the effects of the phase gap generated by the frequency domain PLL and the phase gap generated by the time domain PLL on the results are avoided and the accuracy of carrier phase tracking for OFDM symbols is further improved.

[0121] Based on any of the above-mentioned embodiments, in an embodiment, the apparatus further includes a first fixed phase gap determination module and a second fixed phase gap determination module.

[0122] In an embodiment, the first fixed phase gap determination module is used to determine the first fixed phase gap based on a parameter value of a loop filter in the frequency domain PLL, a subcarrier spacing, and the estimated value of delay occurring in the current OFDM symbol; and the second fixed phase gap determination module is used to determine the second fixed phase gap based on the first fixed phase gap, the inter-symbol phase average offset, and a parameter value of a loop filter in the time domain PLL.

[0123] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0124] In the carrier phase tracking apparatus for OFDM multi-carrier system provided by the embodiments of the present disclosure, by determining the phase gap generated by the frequency domain PLL according to the parameter value of the loop filter in the frequency domain PLL, the subcarrier spacing, and the estimated value of delay occurring in the current OFDM symbol, the determined phase gap generated by the frequency domain PLL is more accurate; and by determining the phase gap generated by the time domain PLL according to the correlation between the frequency domain PLL and the time domain PLL, the determined phase gap generated by the time domain PLL is more accurate, and the accuracy of tracking carrier phase of OFDM symbols is further improved.

[0125] Based on any of the above-mentioned embodiments, in an embodiment, when the apparatus is applied to an OFDM multi-carrier system in the TDD mode, the apparatus further includes a second compensation module.

[0126] In an embodiment, the second compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to an integer ambiguity change, where the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, the current segment downlink received signal is a segment of downlink received signal including the current OFDM symbol.

[0127] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0128] In the carrier phase tracking apparatus for the OFDM multi-carrier system provided by the embodiments of the present disclosure, by compensating the estimated value of the carrier phase of the current OFDM symbol using the integer ambiguity change for the case where the received signal is discontinuous in the TDD system, the accuracy of carrier phase tracking for OFDM symbols is improved.

[0129] Based on any of the above-mentioned embodiments, in an embodiment, the apparatus further includes an uplink frequency offset estimation module and an integer ambiguity change determination module.

[0130] In an embodiment, the uplink frequency offset estimation module is used to perform linear estimation on a frequency offset of a target uplink transmitted signal based on a frequency offset estimated value of the current segment downlink received signal and a frequency offset estimated value of the previous downlink received signal, and determine a frequency offset estimated value of the target uplink transmitted signal, where the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal; and the integer ambiguity change determination module is used to determine the integer ambiguity change according to the frequency offset estimated value of the target uplink transmitted signal.

[0131] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0132] In the carrier phase tracking apparatus for the OFDM multi-carrier system provided by the embodiments of the present disclosure, by performing linear estimation on the frequency offset of the uplink signal at the interval using the frequency offset estimated values of the two segments of adjacent downlink signals, and determining the integer ambiguity change according to the frequency offset estimated value of the uplink transmitted signal, the obtained integer ambiguity change is more accurate and the accuracy of carrier phase tacking for OFDM symbols is further improved.

[0133] Based on any of the above-mentioned embodiments, in an embodiment, when the apparatus is applied to the OFDM multi-carrier system in the TDD mode, the apparatus further includes a third compensation module.

[0134] In an embodiment, the third compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap, the second fixed phase gap and the integer ambiguity change, where the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase; and the integer ambiguity change is the difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal including the current OFDM symbol.

[0135] In an embodiment, the carrier phase tracking apparatus for the OFDM multi-carrier system provided by embodiments of the present disclosure is used to perform the method in the above corresponding embodiment. The steps of executing the method described in the above corresponding embodiment by the apparatus provided in the embodiments are the same as those in the above corresponding embodiment, and will not be repeated here.

[0136] In the carrier phase tracking apparatus for the OFDM multi-carrier system provided by the embodiments of the present disclosure, by compensating the estimated value of the carrier phase of the current OFDM symbol according to the fixed phase gap of the frequency domain PLL, the fixed phase gap of the time domain PLL and the integer ambiguity change, the compensating effect is improved and the accuracy of carrier phase tracking for OFDM symbols is further improved.

[0137] FIG. 5 is a schematic structural diagram of an electronic equipment provided by an embodiment of the present disclosure. As shown in FIG. 5, the electronic equipment includes: a processor 501, a communications interface 502, a memory 503, and a communication bus 504. The communications between the processor 501, the communication interface 502, and the memory 503 are realized through the communication bus 504. The processor 501 can call a computer program stored on the memory 503 and executable on the processor 501 to perform the following steps:

performing frequency domain tracking on a received current OFDM symbol and determining a phase of each subcarrier;

analyzing phase curve of all subcarriers and determining an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol, and the second value is an estimated value of a carrier phase of a previous OFDM symbol; and

performing time domain tracking by using the inter-symbol phase average offset as an input phase and determining an estimated value of a carrier phase of the current OFDM symbol.

[0138] In addition, when the above-mentioned logic instructions in the memory 503 can be implemented in the form of a software functional unit and sold or used as an independent product, it may be stored in a computer-readable storage medium. Based on this understanding, the solutions of the present disclosure in essence or the part of the solutions that contributes to the related art or part of the solutions can be embodied in the form of a software product, and the computer software product is stored in a storage medium, and includes several instructions to cause a computer device (which can be a personal computer, a server, or a network device or the like) to execute all or part of the steps of the methods described in the various embodiments of the present disclosure. The foregoing storage medium includes: USB flash memory, removable hard disk, read-only memory (ROM), random access memory (RAM), magnetic disk or optical disk and other mediums that can store program codes.

[0139] Embodiments of the present disclosure further provide a computer program product, where the computer program product includes a computer program stored on a non-transitory computer-readable storage medium, the computer program includes program instructions, and when the program instructions are executed by a computer, the computer can perform the steps in the above-mentioned method embodiments, including:

performing frequency domain tracking on a received current OFDM symbol and determining a phase of each sub-carrier;
analyzing a phase curve of all subcarriers and determining an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol, and the second value is an estimated value of a carrier phase of a previous OFDM symbol; and
performing time domain tracking by using the inter-symbol phase average offset as an input phase and determining an estimated value of a carrier phase of the current OFDM symbol.

[0140] Embodiments of the present disclosure provide a non-transitory computer-readable storage medium having a computer program stored thereon, and the computer program, when executed by a processor, causes the processor to perform the steps in the above-mentioned method embodiments, including:

performing frequency domain tracking on a received current OFDM symbol and determining a phase of each sub-carrier;
analyzing a phase curve of all subcarriers and determining an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM the symbol, and the second value is an estimated value of the carrier phase of a previous OFDM symbol; and
performing time domain tracking by using the inter-symbol phase average offset as an input phase and determining an estimated value of a carrier phase of the current OFDM symbol.

[0141] The apparatus embodiments described above are only illustrative, where the units described as separate components may or may not be physically separated, and components displayed as units may or may not be physical units, that is, may be located in one place, or may be distributed to multiple network units. Part or all of the units may be selected according to actual needs to achieve the purpose of the solution in these embodiments. Those of ordinary skill in the art can understand and implement it without creative effort.

[0142] From the description of the above embodiments, those skilled in the art can clearly understand that each embodiment can be implemented by means of software plus a necessary general hardware platform, and certainly can also be implemented by hardware. Based on this understanding, the solutions of the present disclosure in essence or the part of the solutions that contributes to the related art can be embodied in the form of a software product, and the computer software products can be stored in computer-readable storage media, such as ROM/RAM, magnetic disk, optical disk or the like, including several instructions for causing a computer device (which can be a personal computer, a server, or a network device or the like) to perform the methods described in various embodiments or some parts of the embodiments.

[0143] Finally, it should be noted that the above embodiments are only used to illustrate the solutions of the present disclosure, but not to limit them; although the present disclosure has been described in detail with reference to the foregoing embodiments, those of ordinary skill in the art should understand that: they can still modify the solutions described in the foregoing embodiments, or equivalently replace some features thereof; while these modifications or replacements do not make the essence of the corresponding solutions deviate from the scope of the solutions in the embodiments of the present disclosure.

Claims

1. A carrier phase tracking method for an orthogonal frequency division multiplexing, OFDM, multi-carrier system, comprising:

   performing frequency domain tracking on a received current OFDM symbol and determining a phase of each subcarrier;
   analyzing a phase curve of all subcarriers and determining an inter-symbol phase average offset, wherein the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol, and the second value is an estimated value of a carrier phase of a previous OFDM symbol; and
   performing time domain tracking by using the inter-symbol phase average offset as an input phase and determining an estimated value of a carrier phase of the current OFDM symbol.

2. The method of claim 1, wherein the analyzing the phase curve of all subcarriers and determining the inter-symbol phase average offset, comprises:

   analyzing the phase curve of all subcarriers in segments and determining a set of estimated value of inter-subcarrier phase change rate;
   performing cluster analysis on the set of estimated value of inter-subcarrier phase change rate and determining a category containing the largest number of elements;
   averaging elements in the category containing the largest number of elements and determining an inter-subcarrier phase change rate, wherein the inter-subcarrier phase change rate is used to characterize an estimated value of delay occurring in the current OFDM symbol; and
   determining the inter-symbol phase average offset according to the inter-subcarrier phase change rate.

3. The method of claim 1 or 2, wherein after determining the estimated value of the carrier phase of the current OFDM symbol, the method further comprises:
   adaptively adjusting a parameter value of a loop filter in a frequency domain phase locked loop, PLL, according to the estimated value of delay occurring in the current OFDM symbol.

4. The method of claim 1, wherein after determining the estimated value of the carrier phase of the current OFDM symbol, the method further comprises:
   compensating the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap and a second fixed phase gap, wherein the first fixed phase gap is a phase gap generated by a frequency domain phase locked loop, PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; and the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase.

5. The method of claim 4, wherein before the compensating the estimated value of the carrier phase of the current OFDM symbol according to the first fixed phase gap and the second fixed phase gap, the method further comprises:

   determining the first fixed phase gap based on a parameter value of a loop filter in the frequency domain PLL, a subcarrier spacing, and the estimated value of delay occurring in the current OFDM symbol; and
   determining the second fixed phase gap based on the first fixed phase gap, the inter-symbol phase average offset, and a parameter value of a loop filter in the time domain PLL.

6. The method of claim 1, wherein when the method is applied to an OFDM multi-carrier system in a time division duplex, TDD, mode, after determining the estimated value of the carrier phase of the current OFDM symbol, the method further comprises:
   compensating the estimated value of the carrier phase of the current OFDM symbol according to an integer ambiguity change, wherein the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal comprising the current OFDM symbol.

7. The method of claim 6, wherein before the compensating the estimated value of the carrier phase of the current OFDM symbol according to the integer ambiguity change, the method further comprises:

performing linear estimation on a frequency offset of a target uplink transmitted signal based on a frequency offset estimated value of the current segment downlink received signal and a frequency offset estimated value of the previous segment downlink received signal, and determining a frequency offset estimated value of the target uplink transmitted signal, wherein the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal; and
determining the integer ambiguity change according to the frequency offset estimated value of the target uplink transmitted signal.

8. The method of claim 1, wherein when the method is applied to an OFDM multi-carrier system in the TDD mode, after the determining the estimated value of the carrier phase of the current OFDM symbol, the method further comprises:
compensating the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap, a second fixed phase gap and an integer ambiguity change, wherein the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase; and the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal comprising the current OFDM symbol.

9. A carrier phase tracking apparatus for an orthogonal frequency division multiplexing, OFDM, multi-carrier system, comprising:

a frequency domain phase locked loop, PLL, module, used to perform frequency domain tracking on a received current OFDM symbol and determine a phase of each subcarrier;
an inner-loop analysis module, used to analyze a phase curve of all subcarriers and determine an inter-symbol phase average offset, wherein the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value, the first value is a carrier phase value of the current OFDM symbol and the second value is an estimated value of a carrier phase of a previous OFDM symbol; and
a time domain PLL module, used to perform time domain tracking by using the inter-symbol phase average offset as an input phase and determine an estimated value of a carrier phase of the current OFDM symbol.

10. The apparatus of claim 9, wherein the inner-loop analysis module comprises a segment analysis sub-module, a cluster sub-module, a delay estimation sub-module and a phase offset determination sub-module, wherein:

the segment analysis sub-module is used to analyze the phase curve of all subcarriers in segments and determine a set of estimated value of inter-subcarrier phase change rate;
the cluster sub-module is used to perform cluster analysis on the set of estimated value of inter-subcarrier phase change rate and determine a category containing the largest number of elements;
the delay estimation sub-module is used to average elements in the category containing the largest number of elements and determine an inter-subcarrier phase change rate, wherein the inter-subcarrier phase change rate is used to characterize an estimated value of delay occurring in the current OFDM symbol; and
the phase offset determination sub-module is used to determine the inter-symbol phase average offset according to the inter-subcarrier phase change rate.

11. The apparatus of claim 9 or 10, further comprising a parameter adjustment module,
wherein the parameter adjustment module is used to adaptively adjust a parameter value of a loop filter in a frequency domain PLL according to the estimated value of delay occurred in the current OFDM symbol.

12. The apparatus of claim 9, further comprising a first compensation module;
wherein the first compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap and a second fixed phase gap, wherein the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; and the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase.

13. The apparatus of claim 12, further comprising a first fixed phase gap determination module and a second fixed phase gap determination module, wherein:

the first fixed phase gap determination module is used to determine the first fixed phase gap based on a parameter value of a loop filter in the frequency domain PLL, a subcarrier spacing, and an estimated value of delay occurring in the current OFDM symbol; and
the second fixed phase gap determination module is used to determine the second fixed phase gap based on the first fixed phase gap, the inter-symbol phase average offset, and a parameter value of a loop filter in the time domain PLL.

14. The apparatus of claim 9, wherein when the apparatus is applied to an OFDM multi-carrier system in a time division duplex, TDD, mode, the apparatus further comprises a second compensation module,
wherein the second compensation module is used to compensate the estimated value of the carrier phase of the current OFDM symbol according to an integer ambiguity change, wherein the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is a segment of downlink received signal comprising the current OFDM symbol.

15. The apparatus of claim 14, further comprising an uplink frequency offset estimation module and an integer ambiguity change determination module, wherein:

the uplink frequency offset estimation module is used to perform linear estimation on a frequency offset of a target uplink transmitted signal based on a frequency offset estimated value of the current segment downlink received signal and a frequency offset estimated value of the previous downlink received signal, and determine a frequency offset estimated value of the target uplink transmitted signal, wherein the target uplink transmitted signal is an uplink transmitted signal at the interval between the current segment downlink received signal and the previous segment downlink received signal; and
the integer ambiguity change determination module is used to determine the integer ambiguity change according to the frequency offset estimated value of the target uplink transmitted signal.

16. The apparatus of claim 9, wherein when the apparatus is applied to an OFDM multi-carrier system in the TDD mode, the apparatus further comprises a third compensation module,
wherein the third compensation module is used to perform compensation on the estimated value of the carrier phase of the current OFDM symbol according to a first fixed phase gap, a second fixed phase gap and an integer ambiguity change, wherein the first fixed phase gap is a phase gap generated by a frequency domain PLL, and the frequency domain PLL is used to perform frequency domain tracking on a received OFDM symbol; the second fixed phase gap is a phase gap generated by a time domain PLL, and the time domain PLL is used to perform time domain tracking on an input phase; and the integer ambiguity change is a difference obtained by subtracting an integer ambiguity of a previous segment downlink received signal from an integer ambiguity of a current segment downlink received signal, and the current segment downlink received signal is one segment downlink received signal comprising the current OFDM symbol.

17. An electronic device, comprising a processor and a memory storing a computer program that is executable on the processor, the computer program, when executed by the processor, causes the processor to perform steps of the carrier phase tracking method for the orthogonal frequency division multiplexing, OFDM, multi-carrier system according to any one of claims 1 to 8.

18. A non-transitory computer-readable storage medium having a computer program
stored thereon, and the computer program, when executed by a processor, causes the processor to perform steps of the carrier phase tracking method for an orthogonal frequency division multiplexing, OFDM, multi-carrier system according to any one of claims 1 to 8.

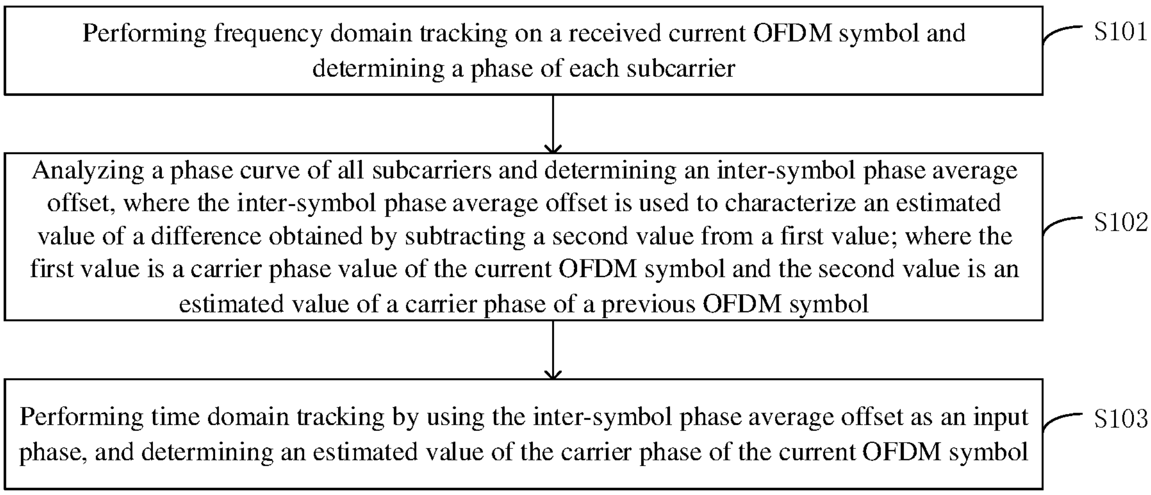
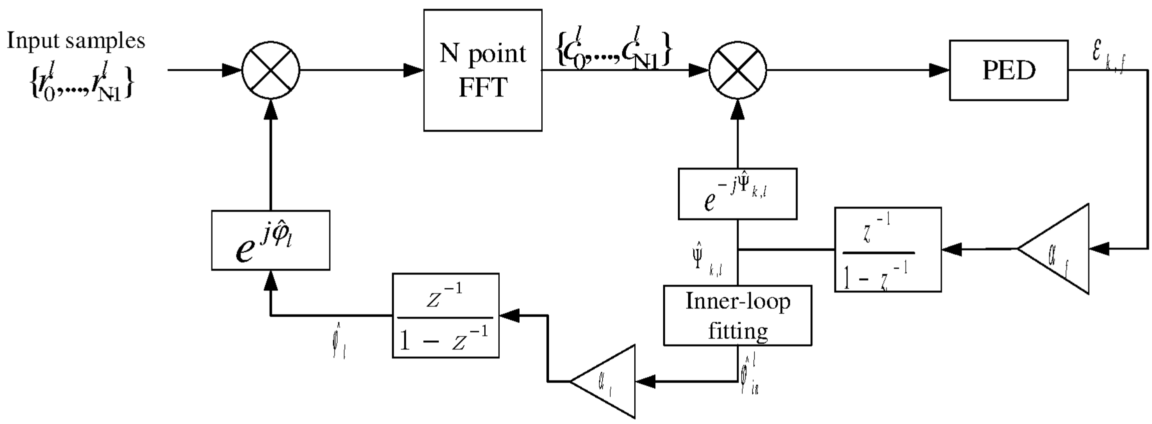

Performing frequency domain tracking on a received current OFDM symbol and determining a phase of each subcarrier
S101
Analyzing a phase curve of all subcarriers and determining an inter-symbol phase average offset, where the inter-symbol phase average offset is used to characterize an estimated value of a difference obtained by subtracting a second value from a first value; where the first value is a carrier phase value of the current OFDM symbol and the second value is an estimated value of a carrier phase of a previous OFDM symbol
S102
Performing time domain tracking by using the inter-symbol phase average offset as an input phase, and determining an estimated value of the carrier phase of the current OFDM symbol
S103

FIG. 1


Input samples
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FFT
PED
Inner-loop
fitting
$\frac{z^{-1}}{1-z^{-1}}$
$e^{j\hat{\varphi}_l}$

FIG. 2

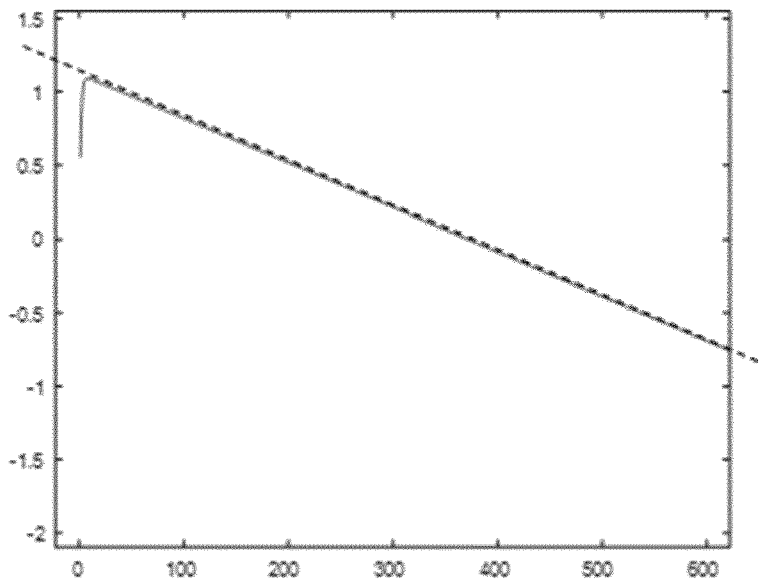

FIG. 3

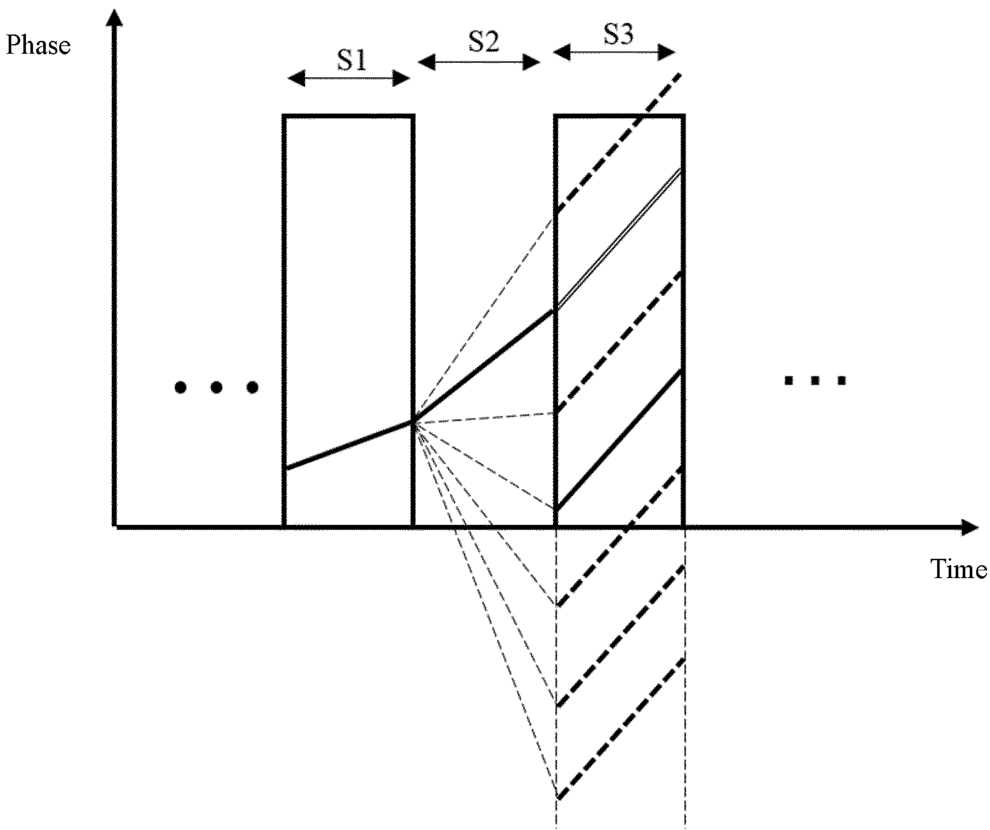

FIG. 4

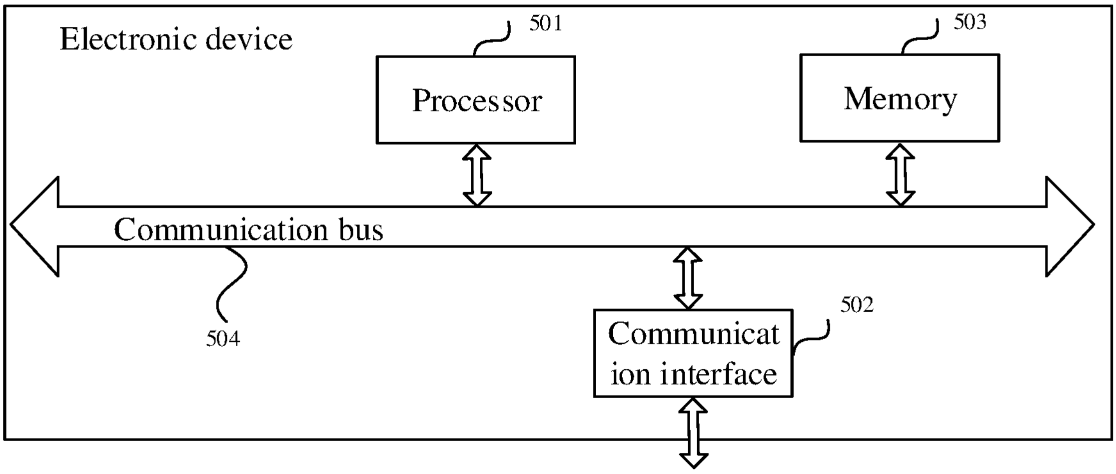
Electronic device
501
503
Processor
Memory
Communication bus
504
502
Communicat
ion interface

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2021/087694

A. CLASSIFICATION OF SUBJECT MATTER

H04B 1/06(2006.01)i; H04L 27/26(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B;H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS; CNTXT; CNKI; VEN; USTXT; EPTXT; WOTXT; 3GPP: 当前, 前一个, 时域, 变化, 补偿, 解卷绕, 偏差, 差, 符号, 符号间, 输入, 跟踪, ofdm, 上一个, 相邻, 频, 频域, 相位, 相位曲线, 时域跟踪, 减, 连续, 偏移, 估计, 误差, 斜率; current, last, change, offset, estimate, adjacent, minus, symbol, curve, error, phase, frequence

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 102349248 A (TYCO ELECTRONICS SUBSEA COMMUNICATIONS, LLC) 08 February 2012 (2012-02-08) description, paragraphs 36-41, figures 5-8	1-18
A	CN 102685064 A (TIANGONG UNIVERSITY) 19 September 2012 (2012-09-19) entire document	1-18
A	US 7251283 B2 (MEDIATEK INC.) 31 July 2007 (2007-07-31) entire document	1-18
A	US 7817736 B2 (TEXAS INSTRUMENTS INC.) 19 October 2010 (2010-10-19) entire document	1-18

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 May 2021	**22 June 2021**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/CN) **No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088** **China**	
Facsimile No. **(86-10)62019451**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2021/087694

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
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				CA	2754761	C	24 May 2016
				EP	2406901	A1	18 January 2012
				JP	5374596	B2	25 December 2013
				JP	5508444	B2	28 May 2014
				EP	2406900	A1	18 January 2012
				US	8295713	B2	23 October 2012
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				CA	2754761	A1	16 September 2010
				CA	2754757	C	10 May 2016
				CA	2754757	A1	16 September 2010
				JP	2012520611	A	06 September 2012
				CN	102349249	A	08 February 2012
				EP	2406901	A4	01 April 2015
				CN	102349249	B	27 August 2014
				US	8340530	B2	25 December 2012
				EP	2406900	A4	01 April 2015
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Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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